Seismic Protective Systems for Computers and Data Processing Equipment

by Tsu T. Soong

Abstract

Data processing installations, intelligent workstations, personal computers and related types of equipment are vital to the successful operation of business, education, research, service and industrial operations in today's world. Any interruption in the operation of data processing or computer equipment can halt or significantly impact the operation of business activity. Especially important are such items as on-line banking, process controls, communications, hospitals and emergency facilities. This scenario, coupled with the occurrence of an earthquake, can lead to total chaos if the computers fail due to the earthquake shock and vibration effects.

In cooperation with IBM and other industrial participants, NCEER researchers have been developing innovative restraining devices (passive, semi-active, and active) for sensitive instruments and equipment. A series of experiments involving computer equipment using some of the innovative support systems as well as conventional systems have been conducted. Some of these innovative support systems show significant performance improvements over conventional systems. The types of innovative devices include: viscoelastic restraints, wire ropes, shape-memory alloy materials, electro-rheological fluid isolation systems, and isolation systems with active or passive control.

The end product of this research effort will be the development of innovative protective systems for computers and sensitive equipment, and formulation of a set of industry-wide guidelines for installation of computer systems, in the form of handbooks or computer code.

Collaboration

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Objectives and Approach

The objective of this research project is to improve the seismic safety of computers and sensitive equipment through the development of innovative protection technology.

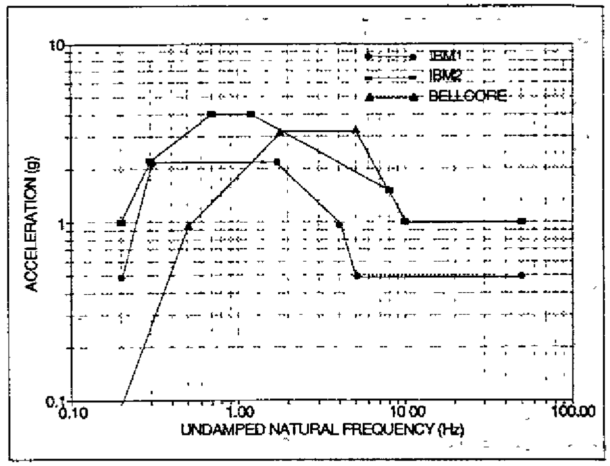
The approach to this research was to perform analytical and simulation studies of the seismic vulnerability of equipment housed in buildings. A performance evaluation of existing methods of installation and restraining devices was undertaken, and protective systems were developed and tested.

This research task is part of NCEER's Nonstructural Components Project. Task numbers are 91-5221, 92-5201 and 93-5202.

Accomplishments

The choice of an appropriate method of installation plays a key role in insuring the seismic safety of computers. As one part of a joint NCEER/IBM research program, seismic tests on a variety of data processing equipment using a wide spectrum of installation methods were conducted in order to assess their effectiveness in preventing or minimizing damaging effects to these equipment in a seismic environment (Kosar, Soong et al., 1993). The methods of installation selected represented a cross section of restraining techniques and covered the range from free casters to innovative energy dissipation devices.

In the test program, horizontal and vertical acceleration measurements using accelerometers were made at many locations on the shaking table, the raised floor, and the equipment being tested.



■ Figure 1
Acceleration response spectra for IBM1, IBM2, and Bellcore inputs

The horizontal displacements of the equipment were measured by means of permanent markers attached to the front and rear surfaces and by temposonic displacement transducers attached to the shaking table and to the equipment.

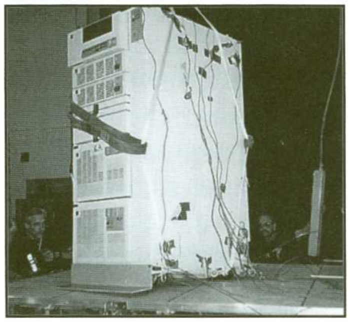
Several types of input accelerations representing some typical past earthquakes and simulated test response spectra were used in the test program. In addition, a test input proposed by Bellcore (Bellcore, 1988) for the upper stories in Zone 4 earthquakes, and two IBM developed inputs (IBM, 1991), were also used. The IBM inputs, denoted by IBM1 and IBM2, represented two functional test levels. At the first level, the machine is expected to operate normally, and at the second level, also referred to as the structural/safety level, gross structural failures should not occur although the machine may not remain functional. The acceleration response spectra of these inputs are shown in figure 1, from which time histories were generated as input accelerations from the shaking table.

A wide variety of IBM mainframe computer systems and peripheral equipment were tested; two of these systems are shown in figure 2. A large number of installation methods as described below were used, representing a cross-section of typical installations as well as innovative passive energy dissipation systems.

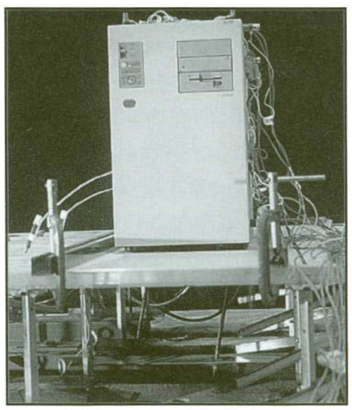
■ *Locked Casters*. The casters were locked into position with thumb screws.The system was otherwise free to swivel and slide on the surface of the raised floor.

■ *Free Casters*. The casters were not locked into position and the system was free to roll on the surface of the raised floor without any external restraint.

IBM 9370 System



IBM 9371 System

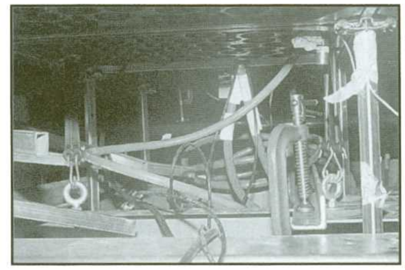


■ Figure 2
Typical computer systems tested

■ *Bungee Cords (with tethers)*. Bungee cords, attached to eye bolts on each side of the rear casters, were secured through two-inch diameter cutout holes in the raised floor to eye bolts attached to steel plates which, in turn, were bolted to the shaking table. A typical installation scheme is shown in figure 3.

■ *Spring Restraints*. Two springs were secured from eye bolts in the floor to eye bolts on either side of the casters via steel cables through the two-inch cut-out holes in the floor.

■ *Toggle Bars*. The toggle bar installation was essentially an adjustable threaded steel rod in tension. Four threaded rods, with turnbuckle adjustment, were attached from the base of the equipment near the casters through two-inch diameter clearance holes in the raised floor. The ends of the toggle bars were attached with steel hooks to eye bolts firmly attached to the floor. In use, the turnbuckles were adjusted to relieve all play in the rods. This installation approximates a fixed base condition, although some limited motion between the equipment and the base is possible because of the clearance hole.

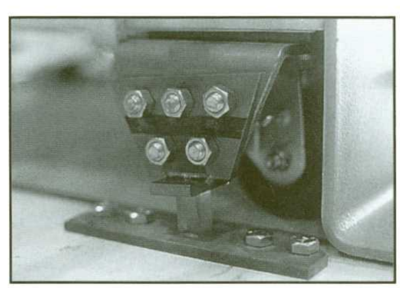


■ Figure 3
Bungee cord installation

■ *Viscoelastic Dampers*. Four viscoelastic dampers, supplied by the 3M Company, were used to secure the system to the surface of the raised floor as shown in figure 4. The design of these dampers allowed direct attachment to the machine. During these tests, the casters were locked with the locking thumb screws.

■ *Wire Ropes*. Four coiled wire rope dampers were bolted directly to the IBM base and the raised floor. The casters were also locked into place during the tests. A typical installation is shown in figure 5 where the foot-plate brace attached to the front of the machine has been removed to permit viewing.

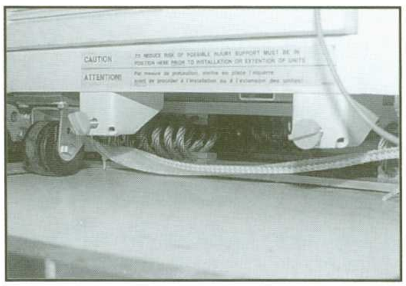
One of the purposes of evaluating the performance of bungee cords, as well as the spring restraints, was to examine the general feasibility of using tethers as a viable installation approach. The advantages of tethers are low cost, and the simplicity and adaptability they affoıd to a variety of field installations.



■ Figure 4
Viscoelastic damper installation

An assessment of the overall

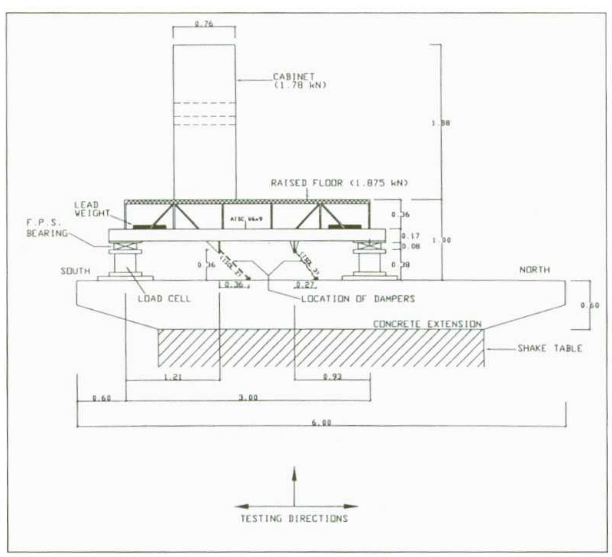
test results indicates that there is a need to formulate installation procedures for computers and data processing equipment according to their dynamic behavior in a seismic environment. It is clear that an optimum restraint system is one which provides, on the one hand, sufficient stiffness to limit lateral displacement of the computer system within an acceptable range and, on the other hand, sufficient damping or energy dissipation capacity to minimize its absolute acceleration. The amount of stiffness and damping of the restraint system required is, in turn, a function of the system characteristics, its location in the structure, the structural characteristics, soil conditions, and seismic conditions at the site. Sufficient knowledge currently exists on the dynamics of these types of systems under the conditions specified above, and this knowledge base can be utilized to develop realistic installation guidelines and efficient restraint systems.



■ **Figure 5**
Wire rope installation

In another direction, innovative installation procedures for computer equipment may also take the form of seismic isolation systems or a form of combined limited isolation and energy dissipation systems. In this way, the seismic forces transmitted to the computer floor may be substantially reduced while normal operations in the computer room are not affected. Another NCEER project concentrated on the development and testing of computer floor seismic isolation systems by utilizing devices of established effectiveness in the seismic isolation of buildings and shock isolation of military equipment (Lambrou and Constantinou, 1994). A computer floor system with raised floor and a generic slender equipment was constructed. It was isolated by spherically shaped sliding bearings and was highly damped either by utilizing high friction in the bearings or by installing fluid viscous dampers. Three different isolation configurations were tested. The Friction Pendulum System (FPS) bearing was the basic component in all three. Four FPS bearings were placed on the top of load cells and supported the base floor. The bearings were installed with the spherical surface facing down. The schematic of the floor system is shown in figure 6.

The spherically shaped bearings provided the simplest means of achieving long periods in the isolation system under low gravity load. The isolation system prevented rocking of the cabinet on top of the isolated floor and substantially reduced its acceleration response in comparison to that of a conventional computer floor. An analytical study was also conducted in order to extend the results to a range of parameters which could not be tested. The experimental and analytical results demonstrated substantial reductions in the response of a generic computer cabinet on top of the isolated floor. Under non-isolated conditions, the tested cabinet underwent rocking and developed accelerations which could cause either interruption of operation or failure. In contrast, the cabinet on the isolated floor with



■ **Figure 6**
Schematic of isolated floor system

a long isolation period (about three seconds) did not experience rocking and developed substantially less acceleration.

Isolation systems combined with active devices have also been a subject of investigation. Since isolation systems exhibit nonlinear behavior, nonlinear and robust control laws have been developed (Yang et al., 1992a,1992b,1993; Subramaniam et al., 1991; Nagarajaiah et al., 1993; Inaudi et al., 1993) and several small-scale hybrid control experiments have been carried out. In one study (Reinhorn et al., 1987; Wang and Reinhorn, 1989), a sliding isolation system was combined with displacement control devices. More recently, a structural model was built and tested with a hybrid control system (Riley et al., 1992,1993; Nagarajaiah et al., 1992). The hybrid system consisted of a series of low friction sliding bearings using highly pressurized teflon interface sliding against stainless steel. The system was developed to reduce the absolute acceleration of the foundation using a variety of control algorithms, from variable friction to acceleration feedback.

Technical References

Bellcore. Network Equipment-Building Systems (NEBS), Generic Equipment Requirements, Report TR-EOP-000063, Issue 3, Whippany, New Jersey, 1988.

Frey, R.A., "Earthquake Testing for Data Processing Equipment," Proceedings, Institute of Environmental Science, 1992.

Frey, R.A. and Nikolsky, G N., "IBM Earthquake Simulation Tests in IBM Mainframe Products," Technical Report No. TR01 C604, Endicott, New York, 1992

IBM, "Earthquake Resistance for IBM Hardware Products," Corporate Bulletin C-B 1-9711-009, Purchase, New York, 1992.

Inaudi, J.A., Kelly, J.M and Pu, J P, "Optimal Control and Frequency Shaping Techniques for Active Isolation," Proceedings, ATC 17-1 Seminar on Seismic Isolation, Passive Energy Dissipation, and Active Control, San Francisco, California, Vol. 2, 1993, pp. 787-798

Kosar, K , Soong, T T , et al , "Seismic Testing of Installation Methods for Computer and Data Processing Equipment," Technical Report NCEER-93-0007, National Center for Earthquake Engineering Research, University at Buffalo, April 12, 1993.

Lambrou, V and Constantinou, M C., "Study of Seismic Isolation Systems for Computer Floors." Technical Report NCEER-94-0020, National Center for Earthquake Engineering Research, University at Buffalo, July 19, 1994.

Nagarajaiah, S., Riley, M., Reinhorn, A and Shinozuka, M , "Hybrid Control of Sliding Isolated Bridges," Proceedings, 1992 Pressure Vessels and Piping Conference, ASME/PVP-237, Vol. 2, 1992, pp. 83-89.

Nagarajaiah, S., Riley, M and Reinhorn, A, "Control of Sliding Isolated Bridge with Absolute Acceleration Feedback," ASCE Journal of Engineering Mechanics, Vol. 119, No. 10, 1993, (in print).

Reinhorn, A M , Soong, T.T and Wen, C.Y., "Base Isolated Structures with Active Control," Proceedings, ASME PVP Conference, San Diego, California, PVP-127, 1987, pp 413-420.

Riley, M.A., Nagarajaiah, S. and Reinhorn, A.M., "Hybrid Control of Absolute Motion in Aseismically Isolated Bridges," Proceedings, Third NSF Workshop on Bridge Engineering Research, University of California, San Diego, 1992, pp 239-242.

Riley, M A , Subramaniam, R , Nagarajaiah, S. and Reinhorn, A M , "Hybrid Control of Sliding Base Isolated Structures," Proceedings, ATC 17-1 Seminar on Seismic Isolation, Passive Energy Dissipation, and Active Control, San Francisco, California, Vol. 2, 1993, pp. 799-810.

Subramaniam, R., Reinhorn, A.M. and Nagarajaiah, S., "Application of Fuzzy Set Theory to the Active Control of Base Isolated Structures." Proceedings U.S./China/Japan Trilateral Workshop on Structural Control, China, 1992, pp. 153-159.

Wang, Y.P. and Reinhorn, A.M , "Motion Control of Sliding Isolated Structures," Seismic, Shock, and Vibration Isolators - 1989, eds H Chung and T. Fujita, ASME/PVP-181, 1989, pp 89-94.

Yang, J.N., Li, Z., Danielians, A. and Liu, S C , "Aseismic Hybrid Control of Nonlinear and Hysteretic Structures I," ASCE Journal of Engineering Mechanics, Vol 118, No 7, 1992a, pp. 1423-1440.

Yang, J N , Li, Z. and Liu, S.C., "Stable Controllers for Instantaneous Optimal Control," ASCE Journal of Engineering Mechanics, Vol. 118, No 8, 1992b, pp. 1612-1630.

Yang, J.N., Li, Z. and Vongchavalitkul, S., "Nonlinear Control of Buildings using Hybrid Systems," Proceedings, ATC 17-1 Seminar on Seismic Isolation, Passive Energy Dissipation, and Active Control, San Francisco, California, Vol. 2, 1993, pp. 811-822.

Publications

Chen, Y.Q. and Soong, T.T. "Seismic Behavior and Response Sensitivity of Secondary Structural Systems," Technical Report NCEER-89-0030, National Center for Earthquake Engineering Research, University at Buffalo, October 23, 1989.

Manolis, G.D., Juhn, G., Constantinou, M.C., and Reinhorn, A.M., "Secondary Systems in Base-Isolated Structures: Experimental Investigation, Stochastic Response and Stochastic Sensitivity," Technical Report NCEER-90-0013, National Center for Earthquake Engineering Research, University at Buffalo, July 1, 1990.

Demetriades, G.F., Constantinou, M.C., and Reinhorn, A.M., "Study of Wire Rope Systems for Seismic Protection of Equipment in Buildings," Technical Report NCEER-92-0012, National Center for Earthquake Engineering Research, University at Buffalo, May 20, 1992.

Kosar, K., Soong, T.T., Shen, K.L., HoLung, J.A., and Lin, Y.K., "Seismic Testing of Installation Methods for Computers and Data Processing Equipment," Technical Report NCEER-93-0007, National Center for Earthquake Engineering Research, University at Buffalo, April 12, 1993.